NACA

RESEARCH MEMORANDUM

ALTITUDE PERFORMANCE OF AN-F-58 FUELS

IN J33-A-21 SINGLE COMBUSTOR

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SUMMARY

An investigation was conducted in a single combustor from a
4600-pound-thrust turbojet engine to determine the altitude per-
formance characteristics of AN-F-58 fuel. Three fuel blends
conforming to the AN-F-58 specification were prepared in order to
determine the influence of fuel boiling temperatures and aromatic
content on altitude performance. The performance of the three
AN-F-58 fuels were compared with the performance of AN-F-32 fuel in
the range of altitudes from 5,000 to 60,000 feet, engine speeds from
50-percent normal rated speed to military rated speed, and flight
Mach numbers of 0.0 and 0.6.

The combustion efficiencies of three AN-F-58 fuels and
AN-F-32 fuel were approximately equal up to altitudes of about
50,000 feet. At higher altitudes some differences occurred. At an
altitude of 60,000 feet, 90-percent normal rated engine speed, and
a flight Mach number of 0.6, a maximum arithmetical difference among
the fuels of 14 percent occurred. The effects of fuel boiling
temperature, as represented by a comparison of two AN-F-58 fuels
differing in final boiling temperature by 30° F (560° to 590° F),
on combustion efficiency were found to be negligible even at the
high altitudes. At the high-altitude condition, the combustion
efficiency of a high-end-point, high-aromatic AN-F-58 fuel was greater
than that of the high-end-point, low-aromatic AN-F-58 fuel, the
differences being more marked at a flight Mach number of 0.6 than
at a flight Mach number of 0.0. These differences cannot be
attributed solely to a change in aromatic content inasmuch as the
boiling temperatures in the middle distillation range of the two
fuels also differ.

Although the altitude-operational-limit data are rather
inconclusive, the operable speed range apparently tends to increase
as the fuel boiling temperatures in the middle of the distillation
range are increased.

INTRODUCTION

The potential availability of AN-F-32 fuel for jet-propulsion
engines is relatively small because of limitations in boiling tem-
peratures and composition. In order to increase the potential supply
of fuel for jet-propulsion engines, AN-F-58, which has wider speci-
fication limits, has been proposed. A comprehensive program was
undertaken at the NACA Lewis laboratory to determine the performance
characteristics of fuels conforming to AN-F-58 specification in
current turbojet engines and single combustors from these engines.

In the single-combustor investigations, special attention was
given to the influence of physical properties of AN-F-58 fuel on
combustor performance in order to determine whether the limitations
on physical properties in the proposed specification are too liberal
or too restrictive. The effects of boiling temperature and aromatic
concentration within AN-F-58 specification on altitude performance
in a single combustor from a 4600-pound-thrust turbojet engine are
presented. Combustion efficiencies and altitude operational limits
were determined in the range of altitudes from 5,000 to 60,000 feet,
engine speeds from 50- to 104-percent (military rating) normal rated
speed, and flight Mach numbers of 0.0 and 0.6.

Comparisons of AN-F-58 fuels with an AN-F-32 fuel were also
made at these conditions.

FUELS

Specifications and analyses for the AN-F-58 fuels and the
AN-F-32 fuel used in this investigation are presented in table I.

Three fuels conforming to AN-F-58 specification were used. The
first of these (NACA fuel number 48-249) was a uniform mixture of
several tank-car lots of AN-F-58 as received from the supplier. For
purposes of this investigation, this fuel, which boiled between
110° and 560° F and contained 19-percent aromatics, was considered a
base stock. A second AN-F-58 fuel (NACA fuel number 48-258) was
prepared by blending 92 percent of the base stock with 8 percent of
a number 3 fuel oil. The resulting blend boiled between 110°
and 590° F and contained 19-percent aromatics. This blend is herein-
after identified as the high-end-point fuel. Comparisons of these
two fuels (NACA fuel numbers 48-249 and 48-258) were intended to
indicate the effect of boiling temperature on turbojet-engine per-
formance.

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A third AN-F-58 fuel (NACA fuel number 48-279) was prepared by
blending 79 percent of the base stock with 13-percent redistilled
hydroformate bottoms and 8-percent number 3 fuel oil. The resulting
fuel blend, which boiled between 110° and 590° F and contained
29-percent aromatics, approaches the AN-F-58 specification limits
of final boiling temperature and aromatic content. This blend is
hereinafter identified as the high-aromatic fuel. Comparisons of
this fuel (NACA fuel number 48-279) with NACA fuel number 48-258
were intended to indicate the influence of aromatic content on
turbojet-engine performance. The addition of the hydroformate
bottoms, however, increased the boiling temperatures throughout most
of the distillation range (cf. NACA fuel numbers 48-258 and 48-279,
table I) and therefore any influence this fuel may have on turbojet-
engine performance may not be due solely to aromatic content.

Inasmuch as the silica-gel determination for aromatic content
(table I) is considered more reliable than A.S.T.M. determinations
for AN-F-58 fuels, all aromatic concentrations referred to will be
by the silica-gel method.

APPARATUS

A single-combustor assembly of a J33-A-21 engine was connected
to the laboratory air-supply and exhaust facilities (fig. 1) and
was equipped with the necessary instrumentation to give total-
pressure and temperature readings both upstream and downstream of
the combustor (figs. 2 and 3). The downstream temperature measure-
ments were obtained from 16 chromel-alumel thermocouples connected
in parallel, thereby giving an instantaneous average exhaust-gas-
temperature reading. These thermocouples were located in a plane
approximately 28 inches from the fuel nozzle, a position approxi-
mately equivalent to the turbine inlet of the engine. The fuel flow
was measured by a flowmeter, which was calibrated for each fuel.

PROCEDURE

The operating conditions simulated engine operation over a
range of engine speeds from 50-percent normal rated speed to military
rated speed, altitudes from 5,000 to 60,000 feet, and at flight Mach
numbers of 0.0 and 0.6. Combustor-inlet air flow, pressures, and
temperatures and combustor-outlet gas temperatures (fig. 4) were
calculated from the engine manufacturer's basic performance curves
for a J33-A-23 engine.

The operation of the combustor consisted of adjusting the inlet air flow, pressure, and temperature for a specific condition and, after initiating combustion, the fuel flow was adjusted until the required combustor-outlet temperature was obtained. After sufficient time was allowed for the combustor and instrumentation to reach equilibrium, all pertinent data were recorded. If the required combustor-outlet gas temperature could not be attained, the condition was considered to be beyond the operational limit.

The combustor was disassembled and cleaned for each series of runs. (A series consisted of all altitude and engine-speed conditions for one fuel at one Mach number.)

Combustion efficiency is defined as the ratio of the enthalpy rise across the combustor to the heating value of the fuel supplied and was calculated by the method described in reference 1.

DISCUSSION OF RESULTS

The data obtained in the investigation of the four fuels are shown in figure 5 as plots of combustion efficiency against engine speed at various altitudes and flight Mach numbers of 0.0 and 0.6. The altitude operational limits encountered for the four fuels are indicated on the figure.

The reproducibility of the data as shown by the duplicate data points in figure 5 was generally within 2 percent. At certain operating conditions, the reproducibility was poorer, especially at 50- and 60-percent normal rated engine speeds at altitudes of 30,000 and 40,000 feet.

Combustion efficiency. - For ease of comparison, data from the faired curves in figure 5 have been replotted in figure 6 to show the variation of combustion efficiency with altitude for the four fuels at two engine speeds.

At 90-percent normal rated engine speed and at both flight Mach numbers, the differences in combustion efficiency of the four fuels at altitudes below 55,000 feet were about equal to or within the limits of reproducibility of the data. At this speed and at an altitude of 60,000 feet, the maximum arithmetical differences in combustion efficiency among the four fuels were about 10 percent at a flight Mach number of 0.0 and 14 percent at a flight Mach number of 0.6.

At low engine speed and Mach number of 0.0 (fig. 6(a)), the
arithmetical differences among the four fuels were negligible. At
low engine speed and Mach number of 0.6 (fig. 6(b)), however, the
maximum arithmetical differences in combustion efficiency were about
7 percent at altitudes of 40,000 and 50,000 feet and about 3 percent
at low altitude.

At the high-altitude conditions where differences do occur
(fig. 6) the combustion efficiency for the base stock AN-F-58 fuel
(48-249) and for the high-end-point AN-F-58 blend (48-258) were
approximately equal. The conclusion is therefore drawn that under
these conditions of operation the variation in boiling temperatures
represented by these two fuels has a negligible effect on combustion
efficiency.

At the high-altitude conditions, the combustion efficiency of
the high-end-point, high-aromatic AN-F-58 blend (48-279) was greater
than that of the high-end-point, low-aromatic AN-F-58 blend (48-258),
the differences being more marked at a flight Mach number of 0.6
than at a flight Mach number of 0.0. These differences cannot be
attributed solely to a change in aromatic content inasmuch as the
boiling temperatures in the middle distillation range of the two
fuels also differ. At altitudes lower than 60,000 feet, the combus-
tion efficiencies of the high-aromatic blend, in general, tend to be
lower than the combustion efficiencies for the other fuels investigated.

At the high-altitude conditions (fig. 6), the combustion
efficiencies of AN-F-32 fuel (48-306) were, in general, about the
same as those for the high-aromatic AN-F-58 fuel (48-279).

Altitude operational limits. - The engine speeds at which
altitude operational limits were encountered for the four fuels
(fig. 5) are summarized in table II with the minimum engine speeds
investigated when no limits were reached.

No minimum operable speed limits were found for the four fuels
at altitudes investigated below 50,000 feet at a flight Mach number
of 0.0. In these cases, engine speeds down to 50 percent of normal
rated speed were simulated. At an altitude of 50,000 feet, limiting
speeds were encountered for the four fuels in the range of engine
speeds from 53 to 58 percent of normal rated speed and at
60,000 feet from 62 to 80 percent of normal rated speed.

At a flight Mach number of 0.6 (table II), minimum operable
speeds were not encountered for the four fuels at altitudes

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investigated below 60,000 feet. The minimum operable speeds for the four fuels at 60,000 feet varied between 60 and 66 percent of normal rated speed.

When the base stock AN-F-58 fuel (NACA fuel number 48-249) is compared with the high-end-point AN-F-58 fuel (NACA fuel number 48-258) at a flight Mach number of 0.0 and altitudes of 50,000 and 60,000 feet, it is seen that increasing the fuel boiling temperatures has extended the operable speed range. That is, the minimum operable speed has been reduced from 58 percent to 53 percent of normal rated and from 80 percent to 76 percent of normal rated speed at altitudes of 50,000 feet and 60,000 feet, respectively. At a flight Mach number of 0.6 and altitude of 60,000 feet, the operable speed ranges of these two fuels are the same.

The high-end-point AN-F-58 fuel (NACA fuel number 48-258) and the high-aromatic AN-F-58 fuel (NACA fuel number 48-279, table II) at an altitude of 50,000 feet and a flight Mach number of 0.0 had the same operable speed ranges. At an altitude of 60,000 feet and at both flight Mach numbers, the high-aromatic fuel had slightly wider operable speed ranges. Inasmuch as the boiling temperatures in the middle distillation range (table I) of the two fuels (NACA fuel numbers 48-258 and 48-279) differ, the preceding effect on altitude limit cannot be attributed solely to the influence of aromatic content.

At an altitude of 60,000 feet, the AN-F-32 fuel (NACA fuel number 48-306) had wider operable speed ranges than the AN-F-58 fuels.

Although the data for the four fuels in table II are rather inconclusive, the operable speed range apparently tends to increase as the fuel boiling temperatures in the middle of the distillation range are increased. (See table I.)

SUMMARY OF RESULTS

From an investigation of the effects of fuel properties on altitude performance in a single combustor from a 4600-pound-thrust turbojet engine, the following results were obtained at simulated engine conditions of 5,000 to 60,000 foot altitude, 50-percent normal rated speed to military rated speed, and flight Mach numbers of 0.0 and 0.6:

1. The combustion efficiencies of three AN-F-58 fuels and
AN-F-32 fuel were approximately equal up to altitudes of about
50,000 feet. At higher altitudes some differences occurred; at an
altitude of 60,000 feet, 90-percent normal rated engine speed, and
a flight Mach number of 0.6, a maximum arithmetical difference of
14 percent occurred among the fuels.

2. The effects of fuel boiling temperature, as represented by
comparison of two AN-F-58 fuels differing in final boiling tempera-
ture by 30° F (560° to 590° F), on combustion efficiency were found
to be negligible even at the high altitudes.

3. At the high-altitude conditions, the combustion efficiency
of a high-end-point, high-aromatic AN-F-58 fuel was greater than
that of a high-end-point, low-aromatic AN-F-58 fuel, the differences
being more marked at a flight Mach number of 0.6 than at a Mach
number of 0.0. These differences cannot be attributed solely to a
change in aromatic content inasmuch as the boiling temperatures in
the middle distillation range of the two fuels also differ.

4. Although the altitude-operational-limit data are rather
inconclusive, the operable speed range apparently tends to increase
as the fuel boiling temperatures in the middle of the distillation
range are increased.

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        National Advisory Committee for Aeronautics,
                Cleveland, Ohio.

REFERENCES

1. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Charts
        for the Computation of Combustion and Mixture Temperatures at
        Constant Pressure. NACA TN No. 1086, 1946.

2. Gooding, Richard M., and Hopkins, Ralph L.: The Determination
        of Aromatics in Petroleum Distillates. Paper presented before
        Div. Petroleum Chem., Am. Chem. Soc. (Chicago, Ill.), Sept. 9-13,
        1946, pp. 131-141.

TABLE I - SPECIFICATIONS AND ANALYSIS OF FUELS USED

NACA fuel	Specifications		Analysis			
	AN-F-58	AN-F-32	AN-F-58			AN-F-32
			48-249	48-258	48-279	48-306
A.S.T.M. distillation D 86-46, °F						
Initial boiling point	-----------	-----------	110	110	110	336
Percentage evaporated						
5	-----------	-----------	135	137	133	350
10	-----------	410 (max.)	157	157	164	356
20	-----------	-----------	192	198	215	360
30	-----------	-----------	230	248	273	365
40	-----------	-----------	272	291	327	370
50	-----------	-----------	314	332	370	375
60	-----------	-----------	351	373	407	380
70	-----------	-----------	388	410	437	387
80	-----------	-----------	427	450	464	394
90	425 (min.)	490 (max.)	473	500	501	405
Final boiling point	600 (max.)	572 (max.)	560	590	590	446
Residue, (percent)	1.5 (max.)	1.5 (max.)	1.0	1.0	1.0	1.0
Loss, (percent)	1.5 (max.)	1.5 (max.)	1.0	1.0	1.0	1.0
Freezing point, °F	-76 (max.)	-76 (max.)	< -76	< -76	< -76	------
Accelerated gum, (mg/100 ml)	20 (max.)	8.0 (max.)	2.9	12.4	17.3	0.0
Air-jet residue, (mg/100 ml)	10 (max.)	5 (max.)	2.6	4.8	8.0	1.0
Sulfur, (percent by weight)	0.50 (max.)	0.20 (max.)	0.03	0.04	0.04	0.02
Aromatics, (percent by volume) A.S.T.M. D-875-46T	30 (max.)	20 (max.)	17	17	26	------
Silica gel[a]	-----------	-----------	19	19	29	15
Specific gravity	-----------	0.850 (max.)	0.769	0.775	0.806	0.831
Viscosity, (centistokes at -40° F	10.0 (max.)	10.0 (max.)	2.67	2.94	4.26	------
Bromine number	14.0 (max.)	3.0 (max.)	13.8	13.3	12.4	------
Reid vapor pressure, (lb/sq in.)	5-7	-----------	5.4	5.1	4.8	------
Hydrogen-carbon ratio	-----------	-----------	0.163	0.161	0.150	0.154
Net heat of combustion (Btu/lb)	18,200 (min.)	-----------	18,640	18,690	18,480	18,530
Hydrocarbon analyses (percent by volume)						
Single ring aromatics			15.0	13.2	14.8	------
Fused ring aromatics			3.0	4.1	12.8	------
Unfused two-ring aromatics			0.5	1.5	1.4	------
Olefin			7.1	6.2	5.3	------
Nonaromatic cyclo-paraffin ring			15.7	16.7	14.3	------
Nonaromatic paraffin and paraffin side chain			58.7	58.3	51.4	------

[a]Determined by modified method of reference 2.

TABLE II - ALTITUDE LIMITS AS DETERMINED BY

MINIMUM OPERABLE ENGINE SPEED

Altitude (ft) ↓	NACA fuel number →	Engine speed (percent normal rated)			
		AN-F-58			AN-F-32
		48-249	48-258	48-279	48-306
		50-percent distillation temperature, °F			
		314	332	370	375
		Flight Mach number, 0.0			
40,000		[a]50	[a]50	[a]50	[a]50
50,000		58	53	53	53
60,000		80	76	71	62
		Flight Mach number, 0.6			
50,000		[a]50	[a]50	[a]50	[a]50
60,000		66	66	63	60

[a]No limit, minimum engine speed investigated.

Combustor

Explosion diaphragm

Floor level

Observation windows

Regulating valves

Regulating valves

Cooling-water sprays

Electric combustion-air heater

Air-measuring orifice

Atmospheric or altitude exhaust

Combustion air

NACA
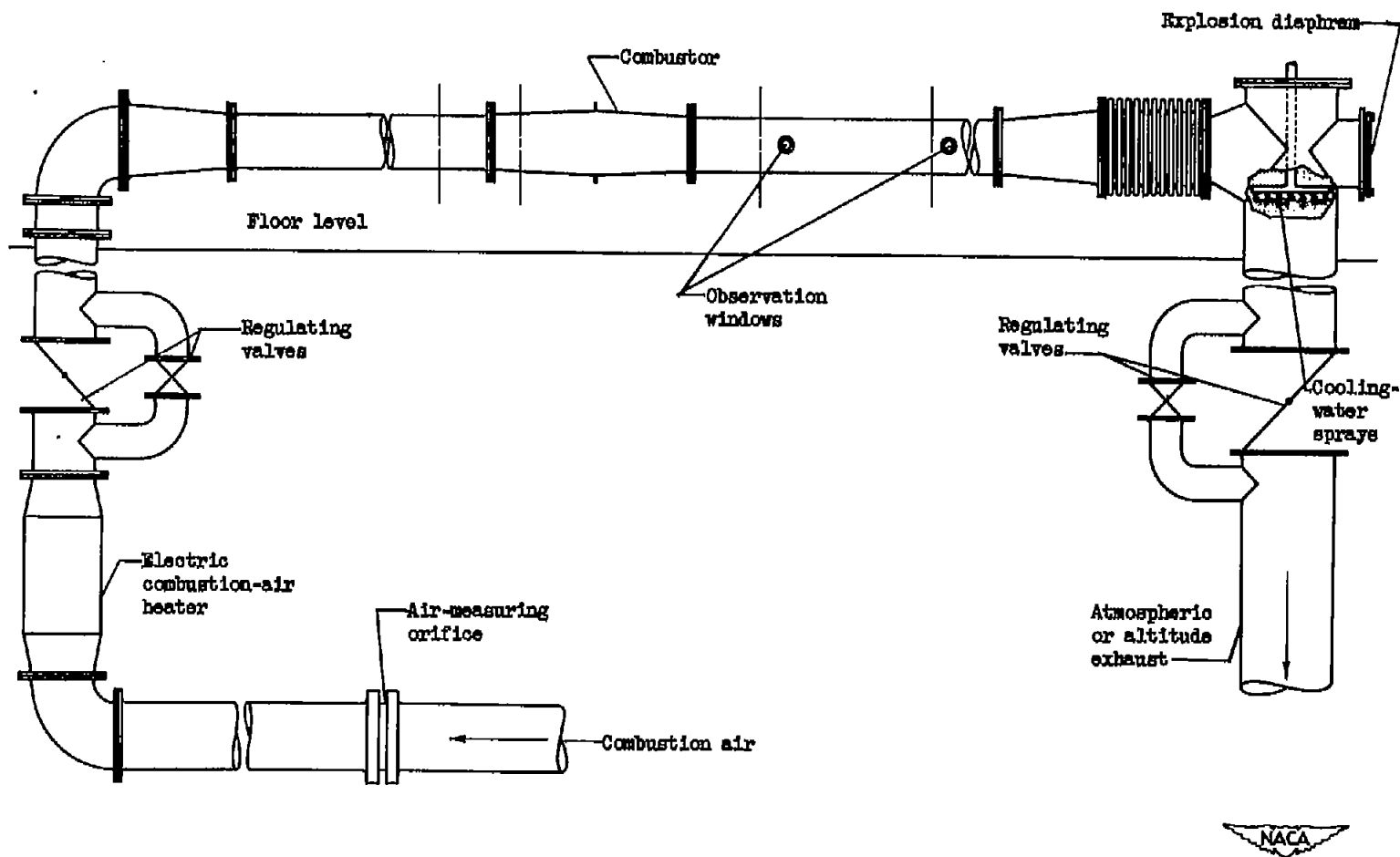
Figure 1. - Single-combustor installation showing inlet and outlet ducting.
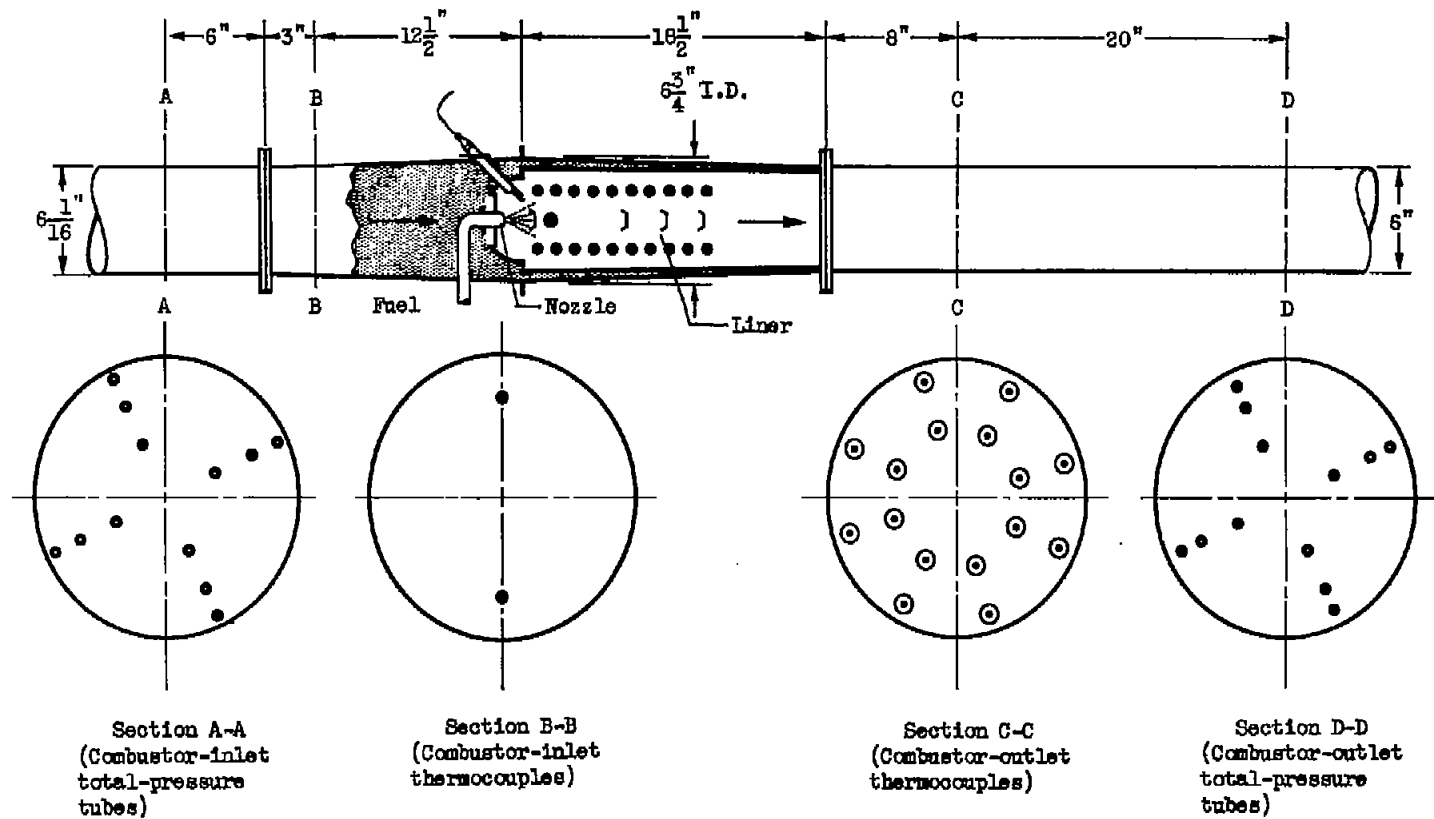
Figure 2. - Detailed sketch of single-combustor installation showing arrangement and location of total-pressure tubes and thermocouples.
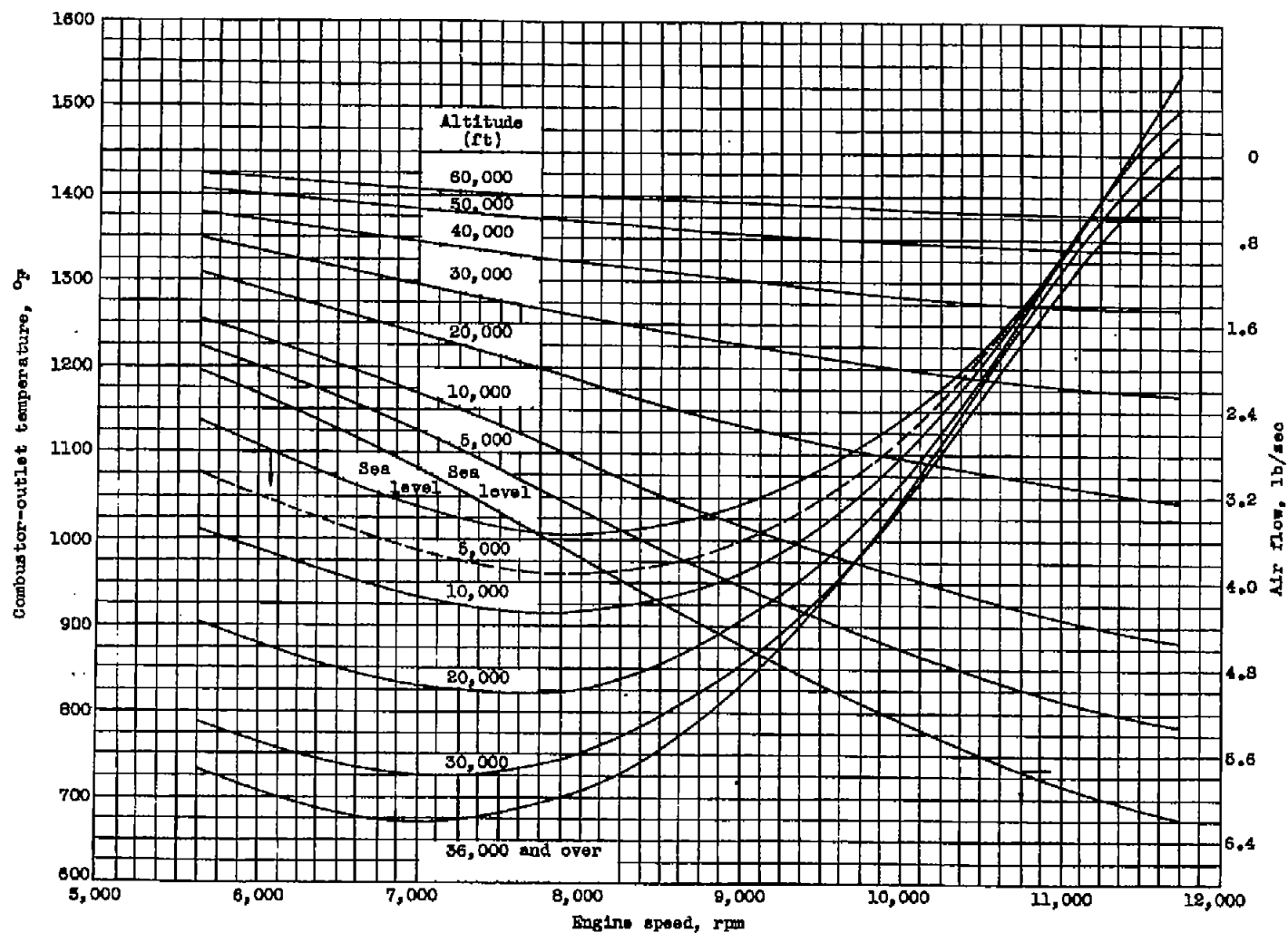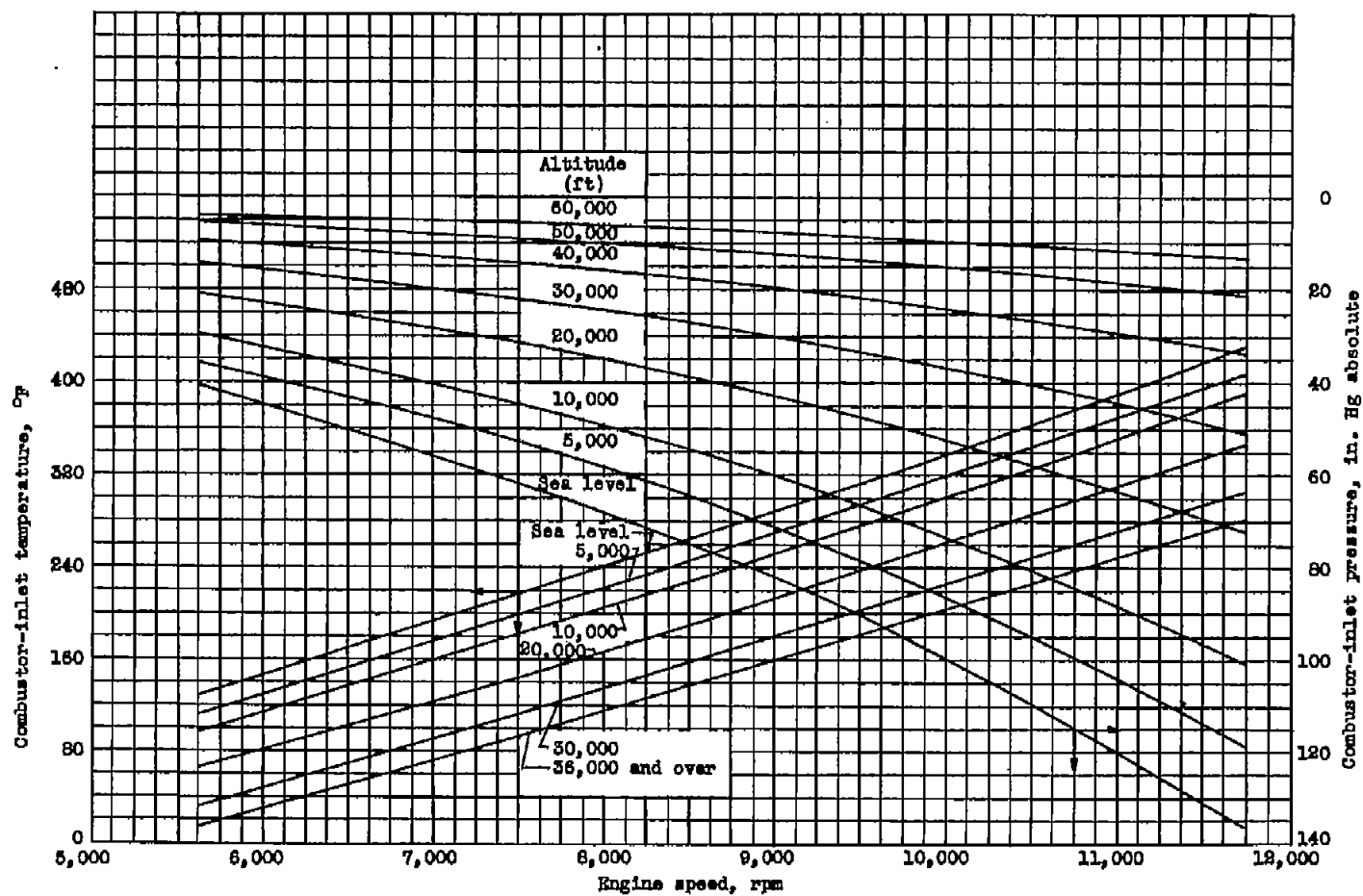
Total-pressure rake
(sections A-A and D-D)

Iron-constantan
thermocouple.
(section B-B)

Chromel-alumel
thermocouples
(section C-C)
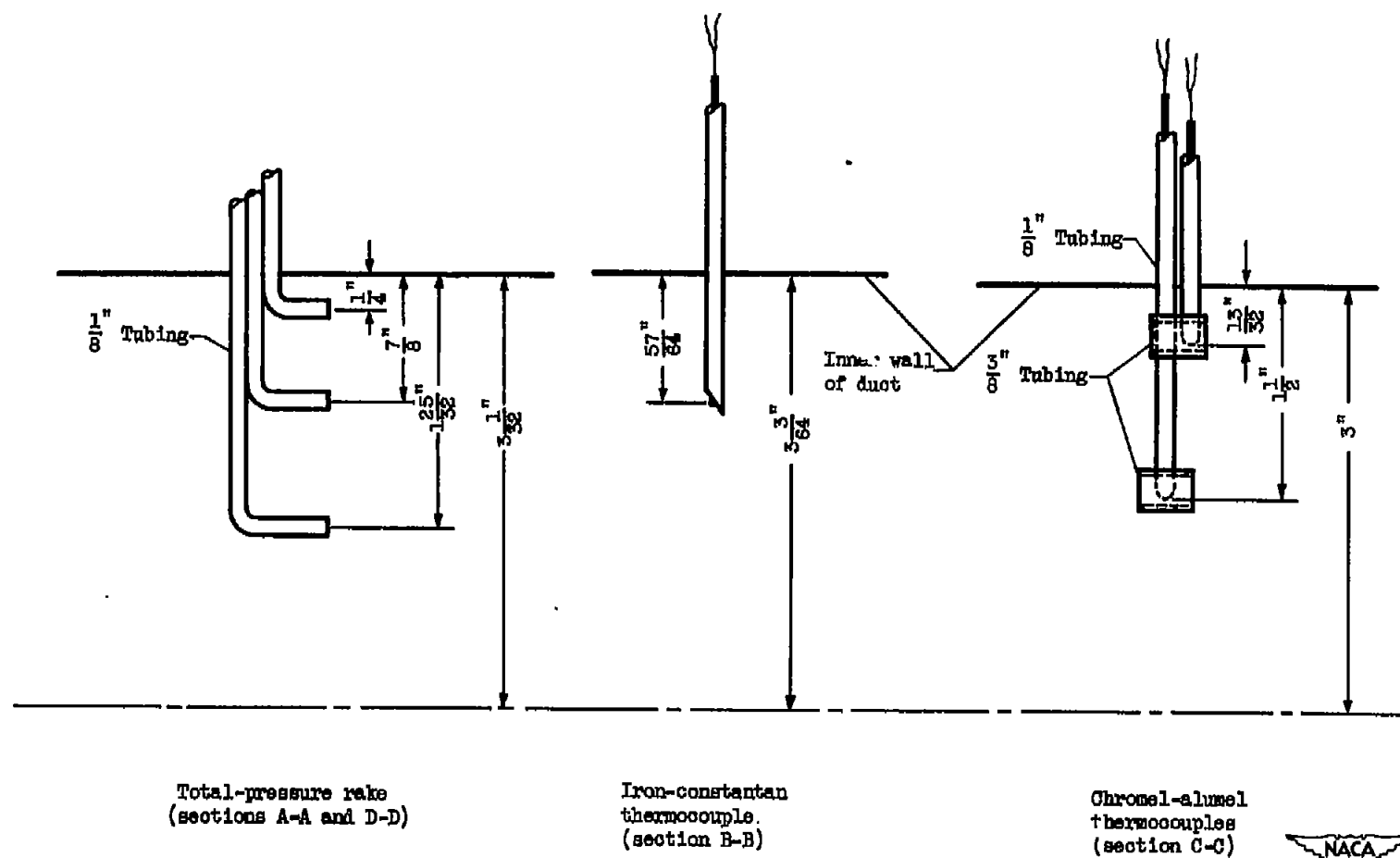
Figure 3. - Design details of total-pressure rakes and thermocouples.

(a) Outlet temperature and air flow. Flight Mach number, 0.0.

Figure 4. - Control chart for single combustor investigated.

(b) Inlet temperature and pressure. Flight Mach number, 0.0.

Figure 4. - Continued. Control chart for single combustor investigated.
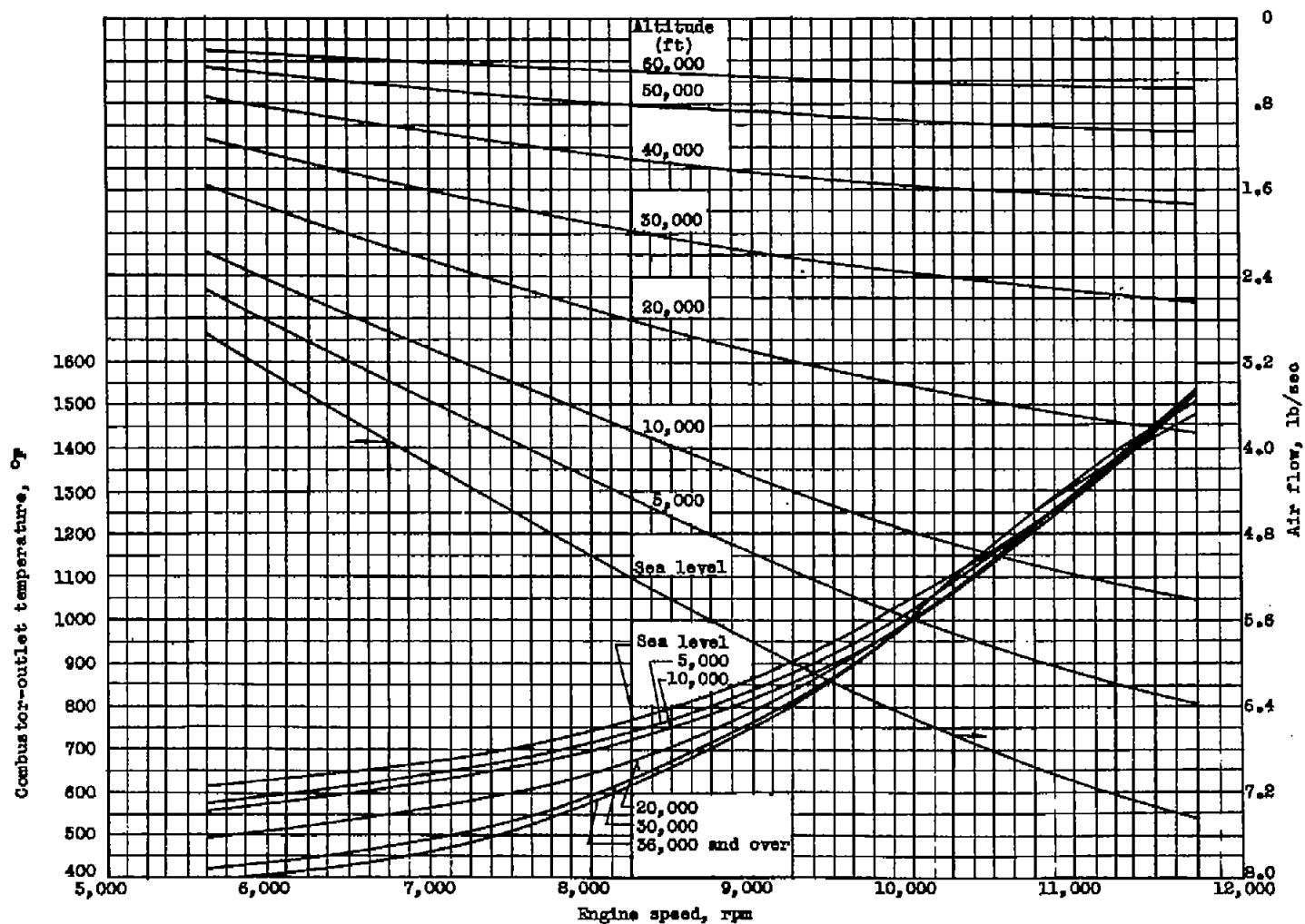
(c) Outlet temperature and air flow. Flight Mach number, 0.5.

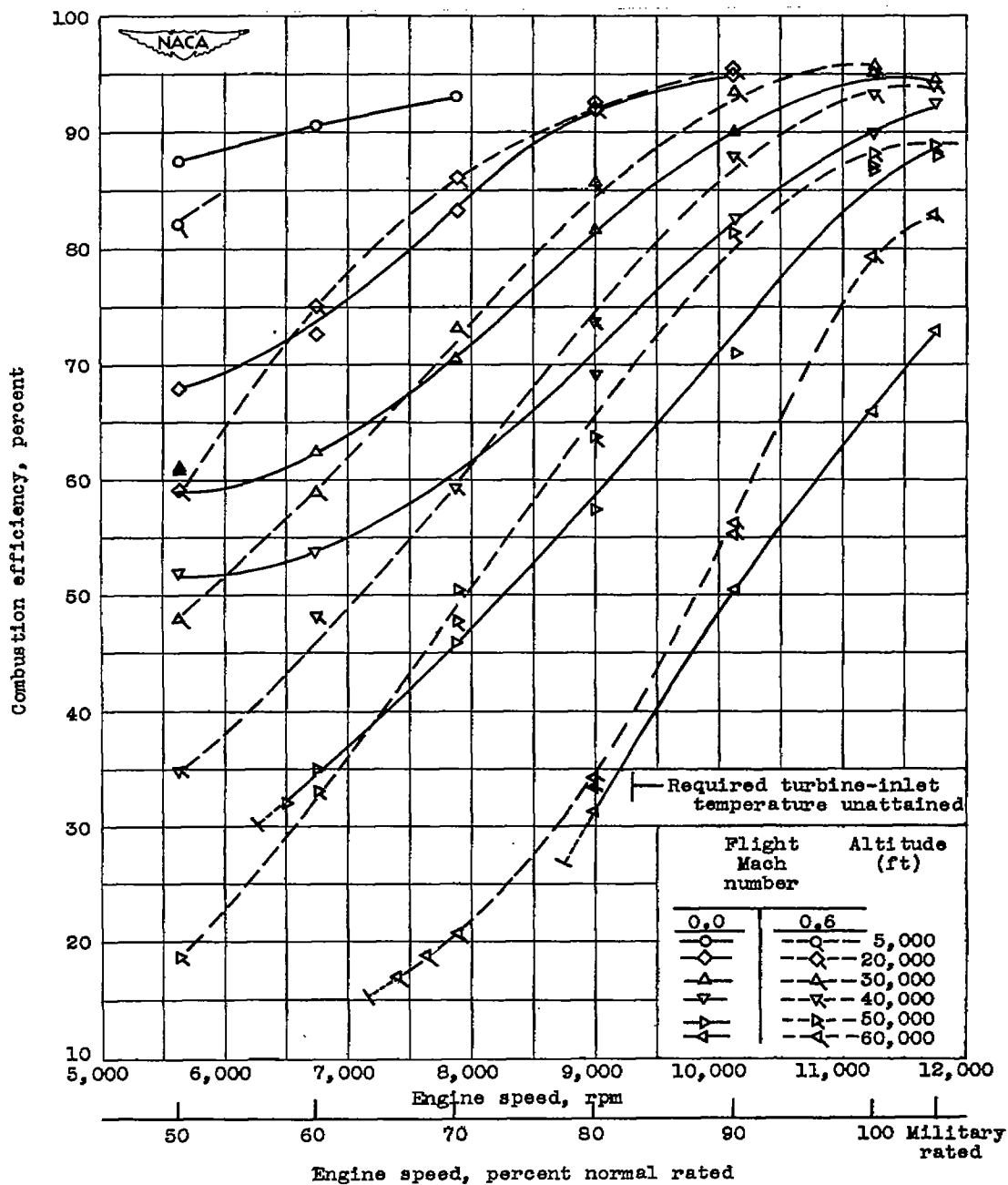Figure 4. - Continued. Control chart for single combustor investigated.
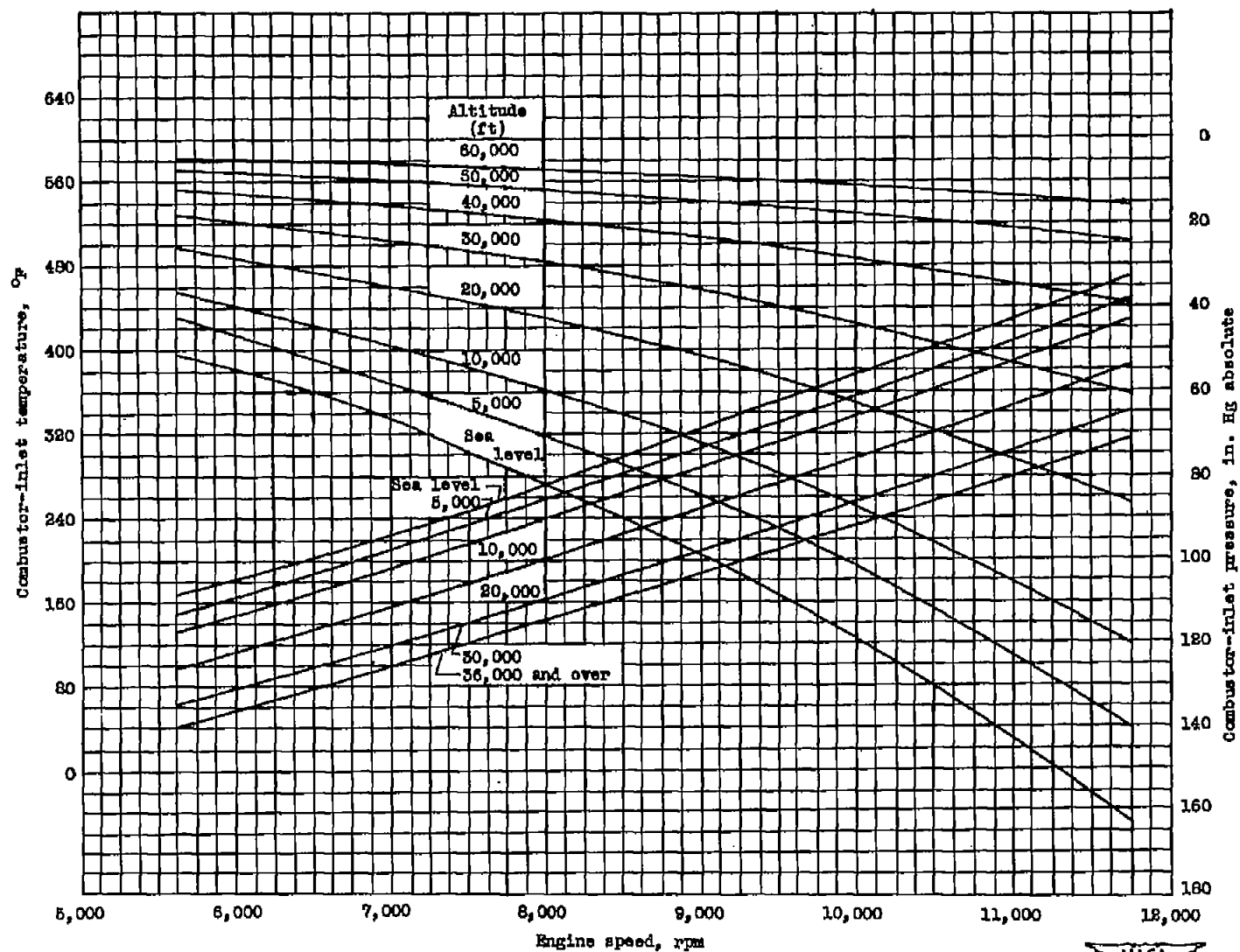
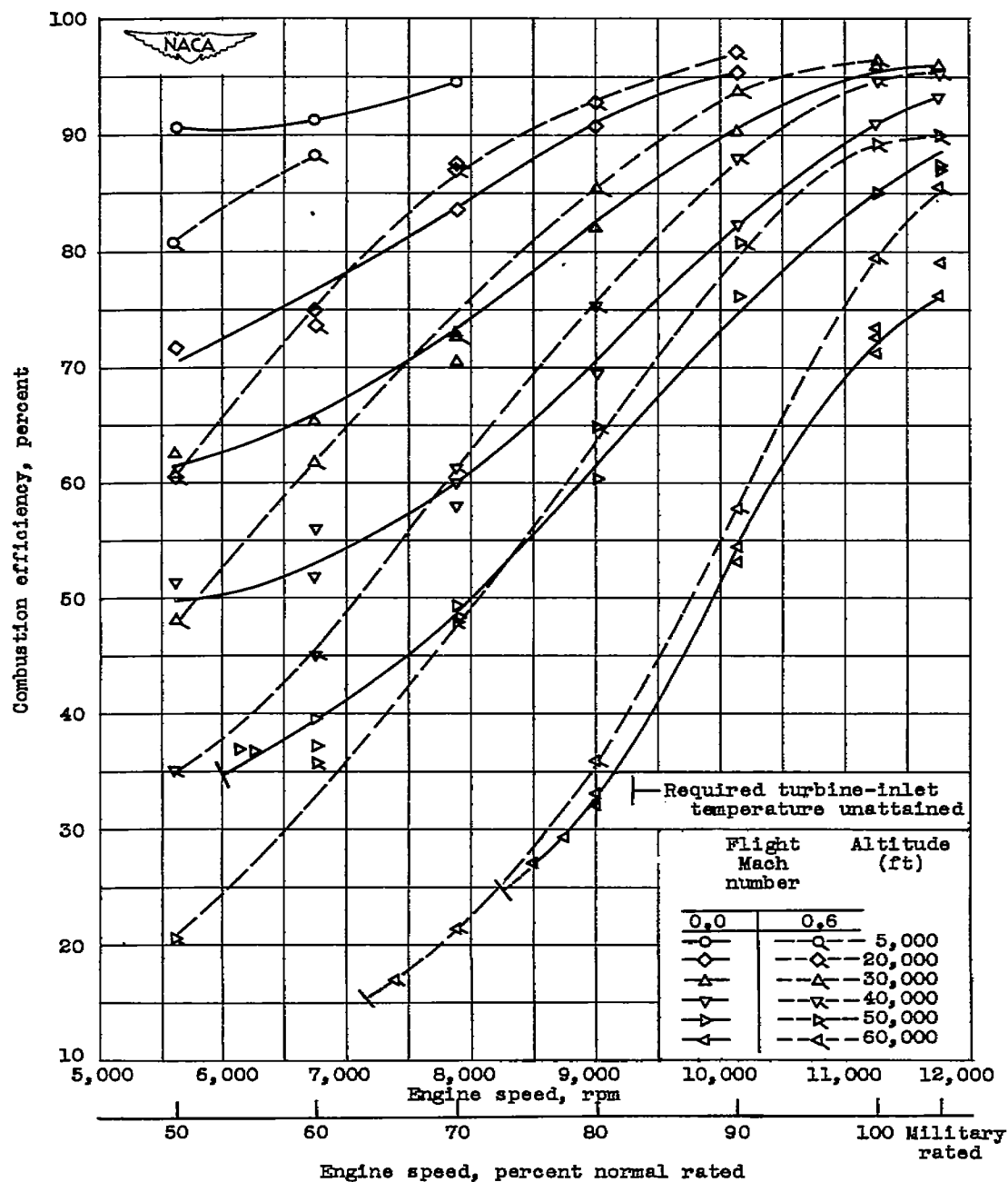(d) Inlet temperature and pressure. Flight Mach number, 0.6.

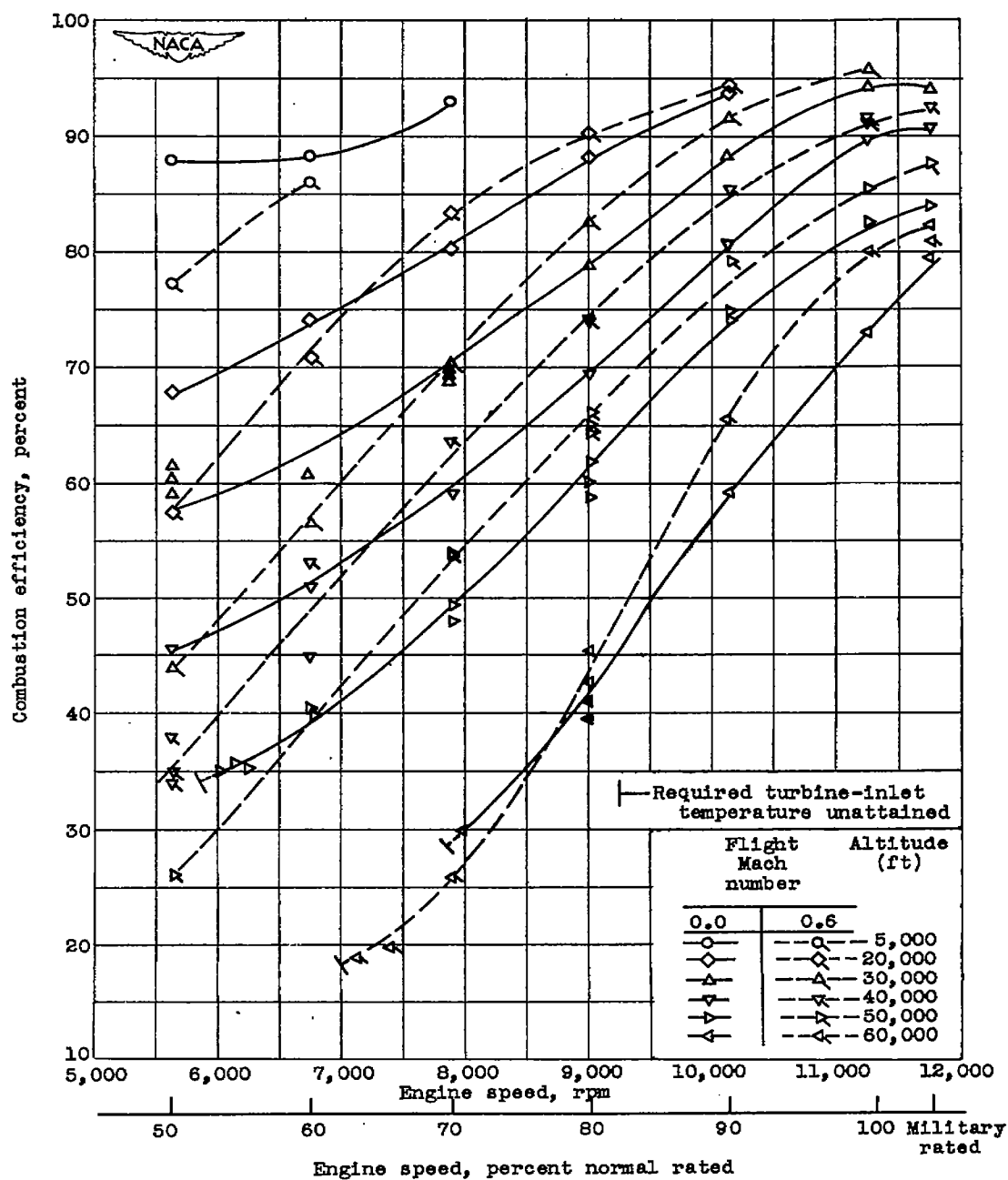Figure 4. - Concluded. Control chart for single combustor investigated.

(a) Fuel, AN-F-58 (NACA fuel number 48-249).

Figure 5. - Effect of flight Mach number on combustion efficiency at various altitudes with engine speed for four fuels in single combustor.
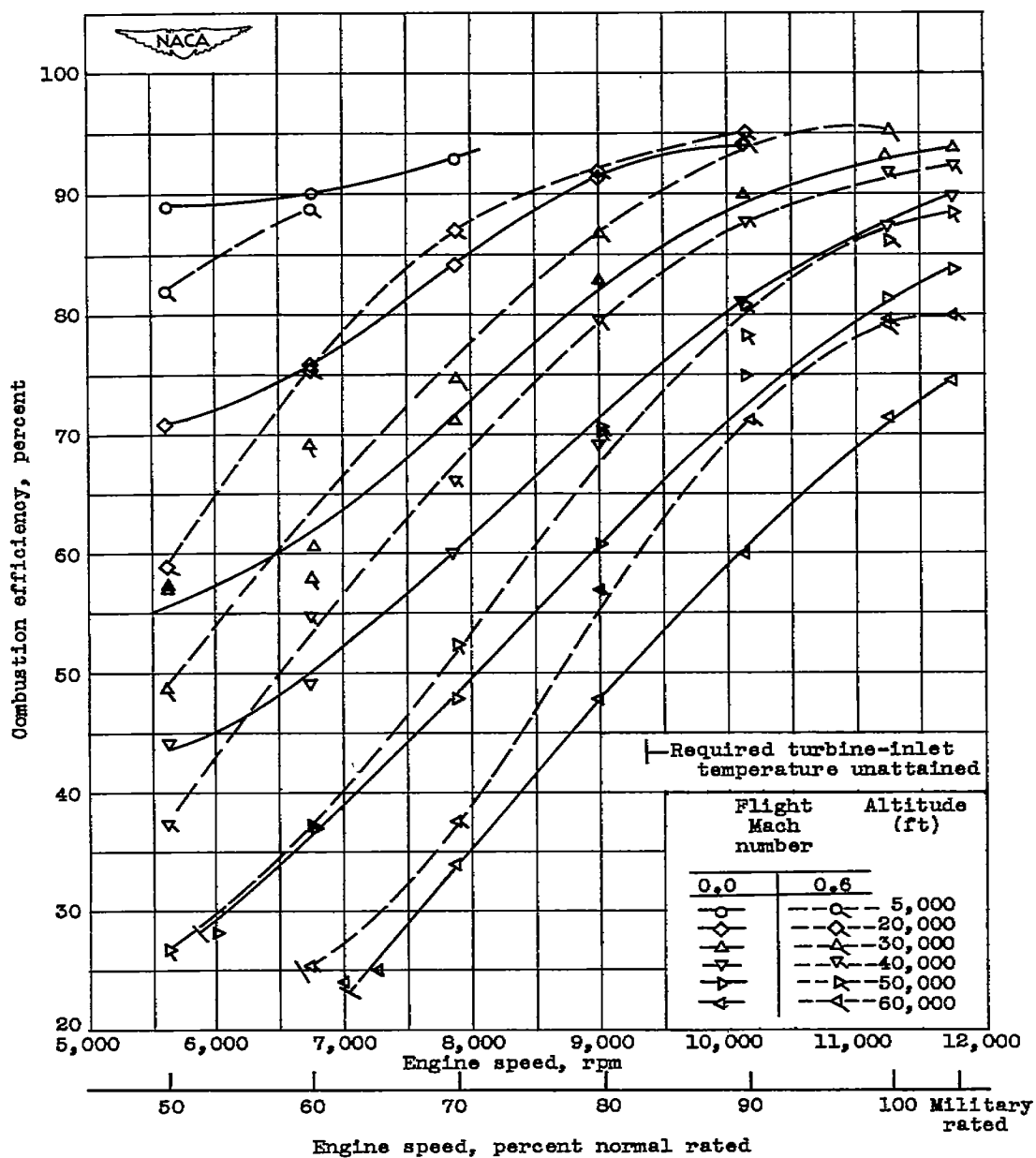
(b) Fuel, AN-F-58 (NACA fuel number 48-258).

Figure 5. - Continued. Effect of flight Mach number on combustion efficiency at various altitudes with engine speed for four fuels in single combustor.

(c) Fuel, AN-F-58 (NACA fuel number 48-279).

Figure 5. - Continued. Effect of flight Mach number on combustion efficiency
at various altitudes with engine speed for four fuels in single combustor.

(d) Fuel, AN-F-32 (NACA fuel number 48-306).

Figure 5. - Concluded. Effect of flight Mach number on combustion efficiency
at various altitudes with engine speed for four fuels in single combustor.
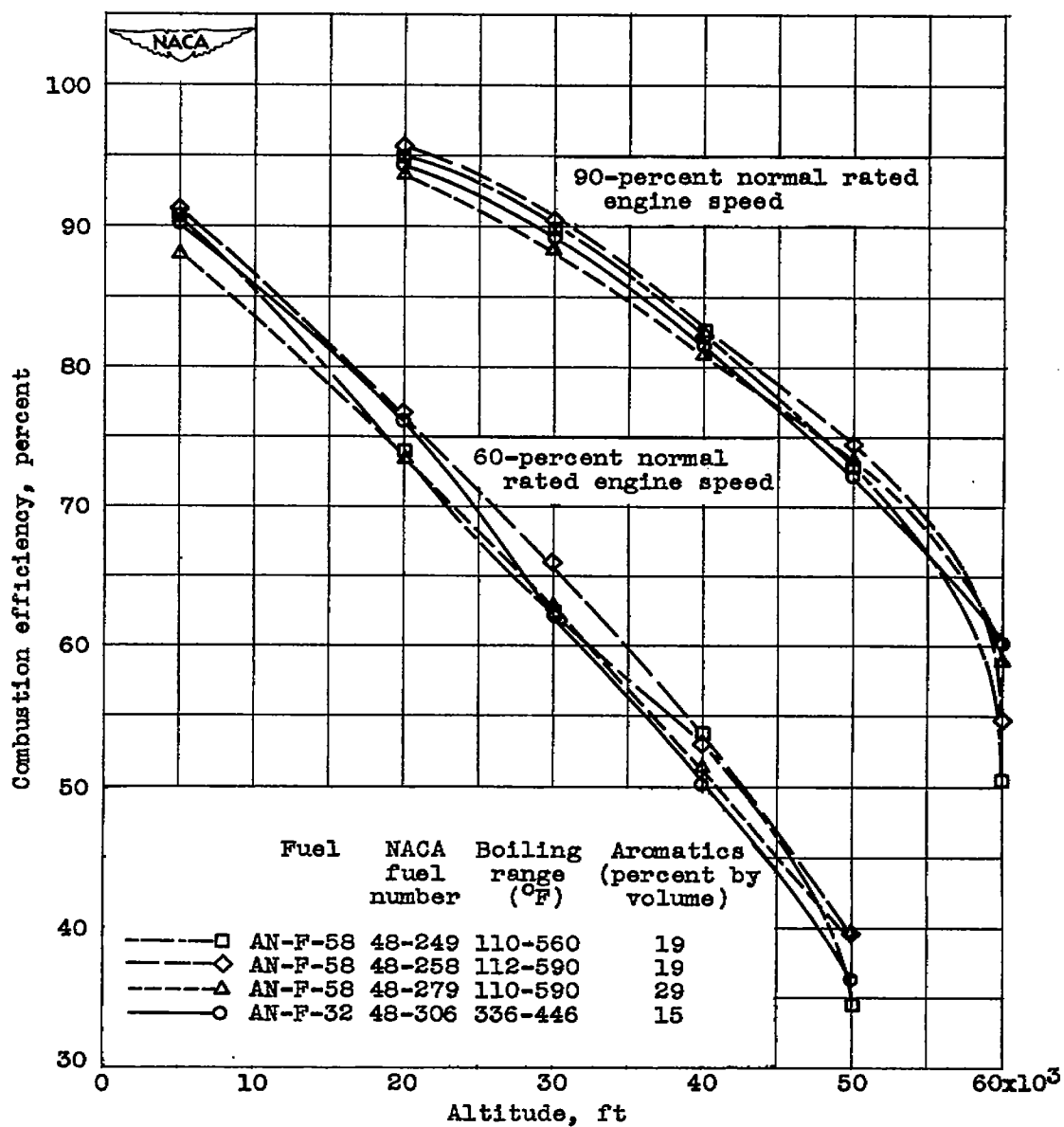
(a) Flight Mach number, 0.0.

Figure 6. - Variation of combustion efficiency at 60- and 90-percent
normal rated engine speed with altitude for single combustor at
two flight Mach numbers.

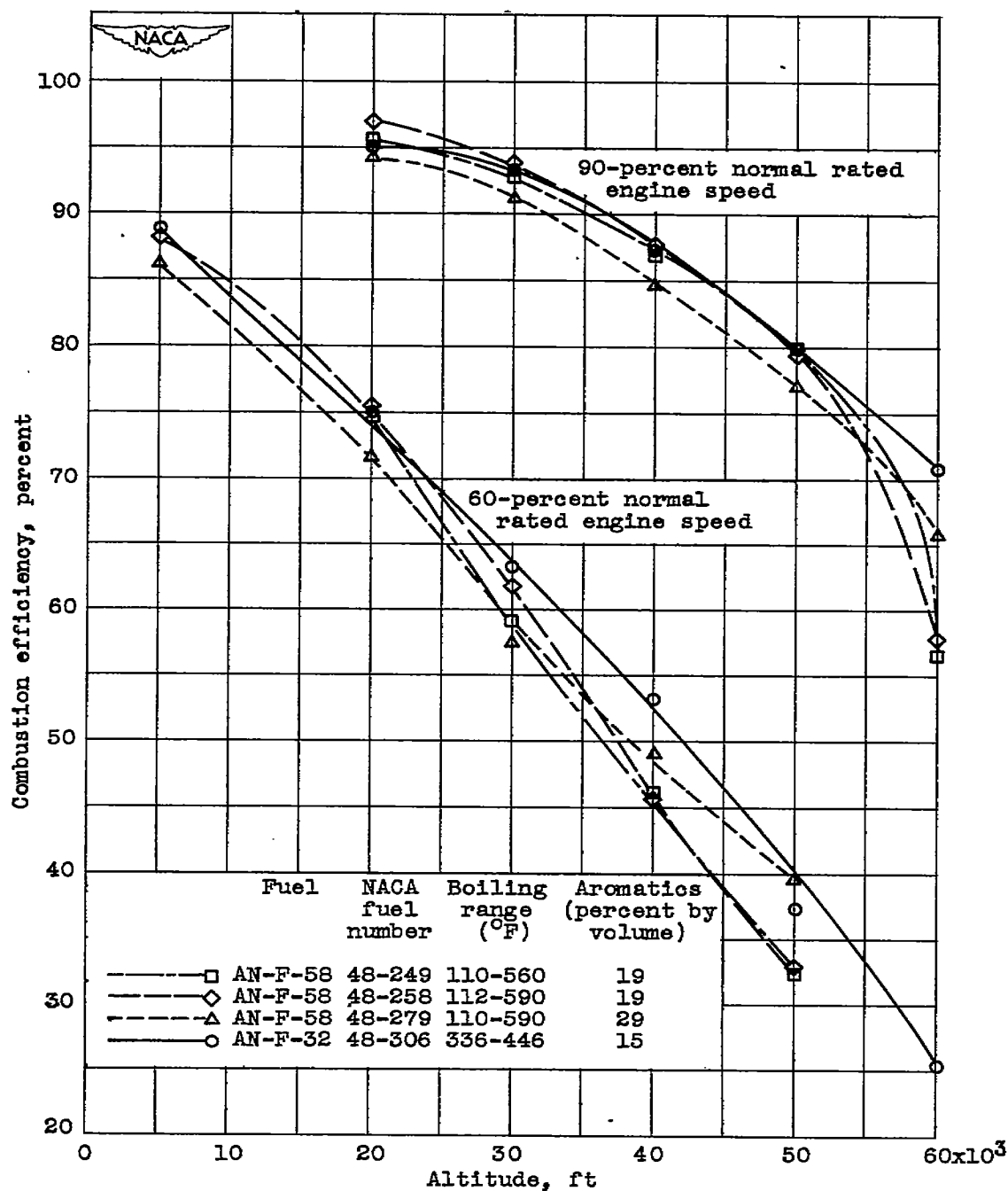| Fuel	NACA fuel number	Boiling range (°F)	Aromatics (percent by volume)
AN-F-58	48-249	110-560	19
AN-F-58	48-258	112-590	19
AN-F-58	48-279	110-590	29
AN-F-32	48-306	336-446	15

(b)   Flight Mach number, 0.6.

Figure 6. - Concluded. Variation of combustion efficiency at 60- and 90-percent normal rated engine speed with altitude for single combustor at two flight Mach numbers.